REC'D 14 JUN 1999
WIPO PCT

PCT/NZ99/00049

Intellectual Property Office of New Zealand
Te Pou Rāhui Hanga Hou

Best Available Copy

CERTIFICATE

5

This certificate is issued in support of an application for Patent registration in a country outside New Zealand pursuant to the Patents Act 1953 and the Regulations thereunder.

I hereby certify that the annexed is a true copy of the Provisional Specification as filed on 23 April 1998 with an application for Letters Patent number 330268 made by Industrial Research Ltd.

Dated 11 May 1999.

Neville Harris

Neville Harris
Commissioner of Patents

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

330268

INTELLECTUAL PROPERTY OFFICE
OF N.Z.
23 APR 1998
RECEIVED

Patents Form No. 4

PATENTS ACT 1953

PROVISIONAL SPECIFICATION

IN LINE AND HYBRID NON-IN-LINE/IN-LINE ROOM ENHANCEMENT SYSTEMS FOR PROVIDING ENHANCED EARLY REFLECTIONS

We, **INDUSTRIAL RESEARCH LIMITED, a New Zealand company, of Gracefield Road, Lower Hutt, New Zealand**
do hereby declare this invention to be described in the following statement:

37797

PRIOR ART

The acoustics of a room has a significant impact on an audience's perception of the quality of a live performance. There are a number of properties of rooms that have been identified as being correlated to subjective impressions of quality. The earliest measured parameter was the reverberation time. This is a global property of the room which has a similar value at all locations. It is governed by the room volume and the absorption of the room surfaces, and the quality of reverberation is also governed by the room shape. Rooms with a long reverberation time can provide a sense of envelopment which produces an increased enjoyment of performances such as opera or classical music. However, the same acoustics can reduce the intelligibility of the spoken word, and is therefore unsuitable for speech.

Other parameters have been determined which relate to the properties of the early part of the response, such as the clarity. More recent auditoria have been designed with reflectors specifically placed to enhance the early part of the room response to sounds emanating from the stage.

To achieve maximum enjoyment of a variety of performances, the acoustics of a room must be matched to the intended performance. Many rooms have for this reason been made acoustically adjustable. For example adjustable absorbers such as moveable curtains or rotatable panels have been used to control reverberation time. Extra acoustic spaces have been constructed which can be coupled to the main area when required to provide more reverberance.

Electroacoustic systems have been used for many years to enhance the acoustics of rooms. The simplest system is the Public Address or sound reinforcement system, In which the sound produced by performers on stage was detected by close microphones and the sound amplified and broadcast from one or more sets of loudspeakers. The goal of such systems was typically to project the direct, unreverberated, sound to the audience to eliminate the effects of the room and improve clarity.

More recently, more complex forms of sound system have been developed which aim to provide adjustable room acoustics. The basic sound reinforcement

system has been further developed by introducing sound processing elements such as delays, which allow the creation of additional sound reflections [1,2]. The delta stereophony system [1] provides sound reflections that are arranged to arrive later than the direct sound, in order to maintain correct localisation. For a given receiver location, the appropriate delays can be chosen to avoid preceding the direct sound, but the delays must be changed for different receiver positions.

The ACS system [2] aims to provide reflections at the appropriate times for all receiver positions, by the creation of wavefronts. The delays are chosen using Huygens principle, and are quantified mathematically by integral equations [3]. The wavefronts are generated using loudspeaker arrays.

These electroacoustic systems offer a more controllable early reflection response than can be achieved using passive reflectors.

Reverberators have also been introduced [4] to provide a larger reverberation time for sources on stage. Larger numbers of speakers have also been employed to provide enhanced reflections and reverberation, such as to under balcony areas. The microphones have also been positioned further from the performers so as to be less obtrusive, while still aiming to detect the direct sound.

The systems discussed above avoid feedback from the loudspeakers to the microphones, since such feedback can lead to colouration and instability if the loop gain is too high. Because of this fact, they may be generically termed in-line, or non-regenerative, systems. Such systems can provide large increases in reverberation for sound sources that are close to the microphones (ie on stage), but they have a small effect for sound sources at other positions in the room.

A second type of enhancement system is the non-in-line, or regenerative, system, which seeks to utilise the feedback between loudspeakers and microphones to achieve a global enhancement of reverberation that occurs for any sound source position [5-8]. Since the natural, unassisted reverberation time is largely the same for all source positions, the regenerative systems can provide a more natural enhanced acoustic. Non-in-line systems use a large number of independent microphone, amplifier, loudspeaker channels, each

with a low loop gain. Each channel provides a small enhancement of reverberation at all frequencies, with low risk of colouration, and the combined effect of all the channels is a significant increase in reverberation and loudness. The microphones are positioned in the reverberant field from all sound sources in the room to ensure that the systems produces a similar enhancement for all sources. Non-in-line systems, however, have typically required from 60 to 120 channels, and have therefore been expensive. Furthermore, since the microphones are remote from all sources, they are less suited to providing significant early reflections than in-line systems.

More recently, a non-in-line system has been developed which uses a multichannel reverberator between the microphones and loudspeakers to provide an increase in reverberation time without requiring an increase in loop gain [9]. It has been shown that the system can both reduce the apparent room absorption (by increasing the loop gain) and increase the apparent room volume (by increasing the reverberation time of the reverberator) [10].

In general, a hybrid room enhancement system may be constructed in which some of the microphones of a non-in-line system containing a reverberator are moved close to the source. In this case the system demonstrates properties of both in-line and non-in-line systems [11].

In any sound system, it is important that the direct acoustic sound from the stage arrives at every member of the audience before (or at the same time as) any electroacoustic signal. This is because the perception of localisation is governed by the first signal to arrive at the ears (provided later signals are not overly large). Hence, care must be taken in both in-line and non-in-line systems to ensure that the electroacoustic signals are suitably delayed. In a non-in-line system this can be achieved by keeping the microphones a suitable distance from the stage. Delays can be used in in-line systems and non-in-line systems to avoid preceding the direct sound. Care must therefore be taken in any non-in-line system where microphones are moved close to the stage.

If a standard multichannel reverberator is inserted in a non-in-line system, the risk of instability is increased. This is because the reverberator has frequency responses whose magnitudes are randomly varying functions of frequency.

Since the reverberator is in a feedback loop, the loop gains effectively have a varying magnitude with frequency. At points where the loop gain is high, instability can occur. In the single channel case, it is obvious that if the feedback function had a flat magnitude with frequency, that the stability would not be compromised. In the multichannel case, the allpass criterion has an equivalent multichannel property termed a *unitary* property. A multichannel reverberator has been developed [12] which has this unitary property which ensures that the total power gain is equal to one at all frequencies. If the reverberator has a matrix of transfer functions **X**(f), then the unitary property states that

$$X^H X = I \qquad 1$$

where the H superscript denotes the conjugate transpose of the matrix. Consider a single frequency f_0 applied to each input of X, with amplitude A_n and phase ϕ_n. The input signal $s_{in}(t)$ may be written

$$s_{in}(t) = e^{j2s\pi f_0 t}\, u \qquad 2$$

where u is the complex amplitude vector

$$u = [A_1 e^{j\phi_1}, A_2 e^{j\phi_2}, \ldots, A_N e^{j\phi_N}]^T \qquad 3$$

The total output power is

$$y^H(t)y(t) = u^H X^H(f_0)X(f_0)u = u^H u \qquad 4$$

since X is unitary. Hence, the power gain of a unitary system is one at all frequencies, and does not affect the stability when inserted into a multichannel system which contains feedback.

INVENTION

Since the reverberation time is a global property of a room, the non-in-line system is best suited to providing a natural enhancement of reverberation, providing it can do so with controlled feedback to minimise colouration.

The in-line system is best suited to the enhancement of early reflections for sources on the stage, since the close positioning of microphones to the sources on stage provides large direct signals. If a reverberator is included, the system provides a reverberation time which is source location dependent, contravening the global nature of reverberation in passive rooms.

When used solely for early reflection enhancement, an in-line system provides a finite number of delayed outputs to simulate early reflections [1,2]. However, if operated at moderate to high gains, the system runs the risk of instability. This is particularly likely if new delays/reflections are added which will increase the frequency dependent loop gain. It is therefore desirable to develop a method for obtaining a finite number of delays without incurring the risk of instability.

In this patent, a novel method of generating early reflections is claimed. The method does not attempt to optimise the delay time for individual receiver positions as in delta stereophony [1]. Nor does it attempt to create wavefronts as in the ACS system. Instead, early reflections are generated in such a way that the stability of the system is maximised. This is achieved by ensuring that the reflection generation circuit has a unitary property. The invention thus amounts to the application of the unitary circuit principles to an in line type early reflection generation system.

The layout of an early reflection system is shown in figure 1. A number of microphones (m_1 to m_N) are positioned close to the sources on stage. The microphone signals are fed to a processor which generates a number of scaled and delayed replicas of the N microphone signals, and the processor outputs are fed to amplifiers and loudspeaker L_1 to L_K placed in the room. The transfer function matrix of the processor is denoted X(f).

The microphones are typically directional, that is, they are sensitive to sound sources positioned on axis, and tend to suppress sound sources (and reflections and reverberation) which are positioned off-axis. This maximises the direct sound pickup and reduces the risk of feedback from the loudspeakers. However, a finite level of feedback still exists, and if the loop gain of the system is too high, the system will become unstable. The transfer function matrix from the loudspeakers to the microphones is H(f), and the loop transfer function matrix is thus H(f)X(f). If the locus of any eigenfunction of H(f)X(f) encircles the point (1+j0), the system will be unstable [11,14].

The stability of the system can be maintained by keeping the loop gain low, for example by keeping the amplifier or microphone preamplifier gains low. However, for a given setting of amplifier gains, the stability of the system is dependent on the particular delay times and delay levels in the processor. Hence, the system stability cannot be guaranteed once the amplifier gains are set.

However, if X(f) has a unitary property, its power gain is unity at all frequencies. The stability is then independent of the delay times and levels.

Unitary early reflection systems may be constructed using non cross coupling delay lines and orthonormal cross coupling matrices. The simplest N channel system comprises N delay lines connecting N microphone signals to N loudspeakers, as shown in figure 2. This system generates a single delay at each output for a signal applied to its respective input. The transfer function matrix is

$$X = D = \begin{bmatrix} \exp\{-j\omega T_1\} & 0 & 0 & 0 \\ 0 & \exp\{-j\omega T_2\} & 0 & 0 \\ 0 & 0 & \exp\{-j\omega T_3\} & 0 \\ 0 & 0 & 0 & \cdots \\ 0 & 0 & 0 & \exp\{-j\omega T_N\} \end{bmatrix} \qquad 5$$

This has a diagonal form since there is no cross coupling. The system is unitary since $D^H D=I$.

By adding orthonormal cross coupling matrices, more complex systems can be obtained. In figure 3, an orthonormal matrix M_1 is placed before the delay lines so that a signal applied to any one input is coupled into every delay line, resulting in a single scaled and delayed replica of that signal at every output. The transfer function matrix is

$$X = DM_1 \tag{6}$$

This system is unitary since both M_1 and D are unitary, and the product of unitary matrices is unitary. A more general system has an orthonormal matrix both before and after the delay lines, as shown in figure 4. Consider a single impulse applied to one of the inputs. The impulse is applied to all N delay line inputs, and appears at times τ_n later at the delay outputs. The N delayed impulse are then cross coupled to every output. Thus, N output delays are generated at each output for a single applied impulse. The circuit thus has the property of diffusing the inputs and providing the maximum number of outputs for any input. The matrix transfer function of the circuit is the product of the transfer function matrices of each section

$$X = M_2 D M_1 \tag{7}$$

More complex unitary systems can be built by cascading multiple systems of the form in figure 4, as shown in figure 5. This system generates N^2 scaled delayed replicas of a signal applied to any single input at every output. Hence the delay density increases rapidly with the number of delay stages.

CLAIMS

1. An in-line early reflection generation system consisting of:
   a number of microphones positioned close to one or more sound sources so as to detect predominantly direct sound;
   a unitary early reflection system which ensures that the stability of the system is independent of the delay times and amplitudes;
   a number of loudspeakers placed to broadcast early reflected energy into the room.

2. An in-line early reflection generation system consisting of:
   a number of microphones positioned close to one or more sound sources so as to detect predominantly direct sound;
   a unitary early reflection system which ensures that the stability of the system is independent of the delay times and amplitudes, and which consists of a plurality of delay lines which are preceded and/or followed by orthonormal cross coupling matrices;
   a number of loudspeakers placed to broadcast early reflected energy into the room.

3. An in-line early reflection generation system consisting of:
   a number of microphones positioned close to one or more sound sources so as to detect predominantly direct sound;
   a unitary early reflection system which ensures that the stability of the system is independent of the delay times and amplitudes, and which consists of a series connection of orthonormal matrices with a set of delay lines positioned between each matrix;
   a number of loudspeakers placed to broadcast early reflected energy into the room.

4. A early reflection generation system consisting of a multichannel, cross coupled, linear system containing an arbitrary number of inputs and outputs, which provides a finite plurality of delayed outputs for every input, with a transfer function matrix which demonstrates a unitary property.

5. A multichannel, cross coupled, linear system containing an arbitrary number of inputs and outputs, which provides a plurality of delayed outputs for every input, and in which each input is directed to every output to provide a maximisation of diffusion of the input signals to all of the outputs, and in such a way that the resulting transfer function matrix has a unitary property.

6. A hybrid room enhancement system comprising:
a non-in-line assisted reverberation system for controlling the global reverberation time of the room such that the reverberation time is similar for all source positions in the room;
an in-line early reflection enhancement system for controlling the early reflections in the room for sound sources in the stage area, and which employs a unitary reflection generation system to provide stable enhancement for a variety of reflection settings.

7. A room enhancement system comprising:
a non-in-line assisted reverberation system for controlling the global reverberation time of the room such that the reverberation time is similar for all source positions in the room, and which employs a unitary multichannel reverberator for providing an enhancement of apparent room volume without an increased risk of colouration or instability;
an in-line early reflection enhancement system for controlling the early reflections in the room for sound sources in the stage area, and which employs a unitary reflection generation system to provide stable enhancement for a variety of reflection settings.

References

1) W. Anhert, "Complex simulation of acoustic fields by the delta sterophony system (DDS)," *J. Audio Eng. Soc.*, vol. 35, no. 9, pp 643-652, September 1987.

2) A. J. Berkhout, "Electro-Acoustical System," US Patent No. 5,142,586, Aug. 25, 1992.

3) A. J. Berkhout, D. de Vries, and P. Vogel, "Acoustic control by wave field synthesis," *J. Acoust. Soc. Am.*, vol. 93, no. 5, pp 2764-2778, May 1993.

4) D. H. Griesinger, "Electroacoustic System," US Patent No. 5,109,419, April 28, 1992.

5) A. Krokstad, "Electroacoustic means of controlling auditorium acoustics," *Applied Acoustics*, vol. 24, pp 275-288, 1998.

6) S. H. de Koning, "The MCR system - multiple-channel amplification of reverberation," *Philips Tech. Rev.*, vol. 41, no. 1, pp 12-23, 1983/84.

7) N. V. Franssen, "Sur l'amplification des champs acoustiques," *Acustica*, vol. 20, pp 315-323, 1968.

8) F. Kawakami and Y. Shimizu, "Active field control in auditoria," *Applied Acoustics*, vol. 31, pp 47-75, 1990.

9) "Wideband assisted reverberation system," PCT Application no. WO 93/23847.

10) M. A. Poletti, "The performance of a new assisted reverberation system," *Acta Acustica*, 2 December 1994, pp 511-524.

11) M. A. Poletti, "The analysis of a general assisted reverberation system," accepted for publication in *Acta Acustica*.

12) "Improvements in Reverberators for use in assisted reverberation systems", PCT application no. NZ94/00110.

13) P. A. Nelson and S. J. Elliot, "Active control of sound," Academic Press, 1992.

RUSSELL McVEAGH WEST-WALKER

per:

ATTORNEYS FOR THE APPLICANT

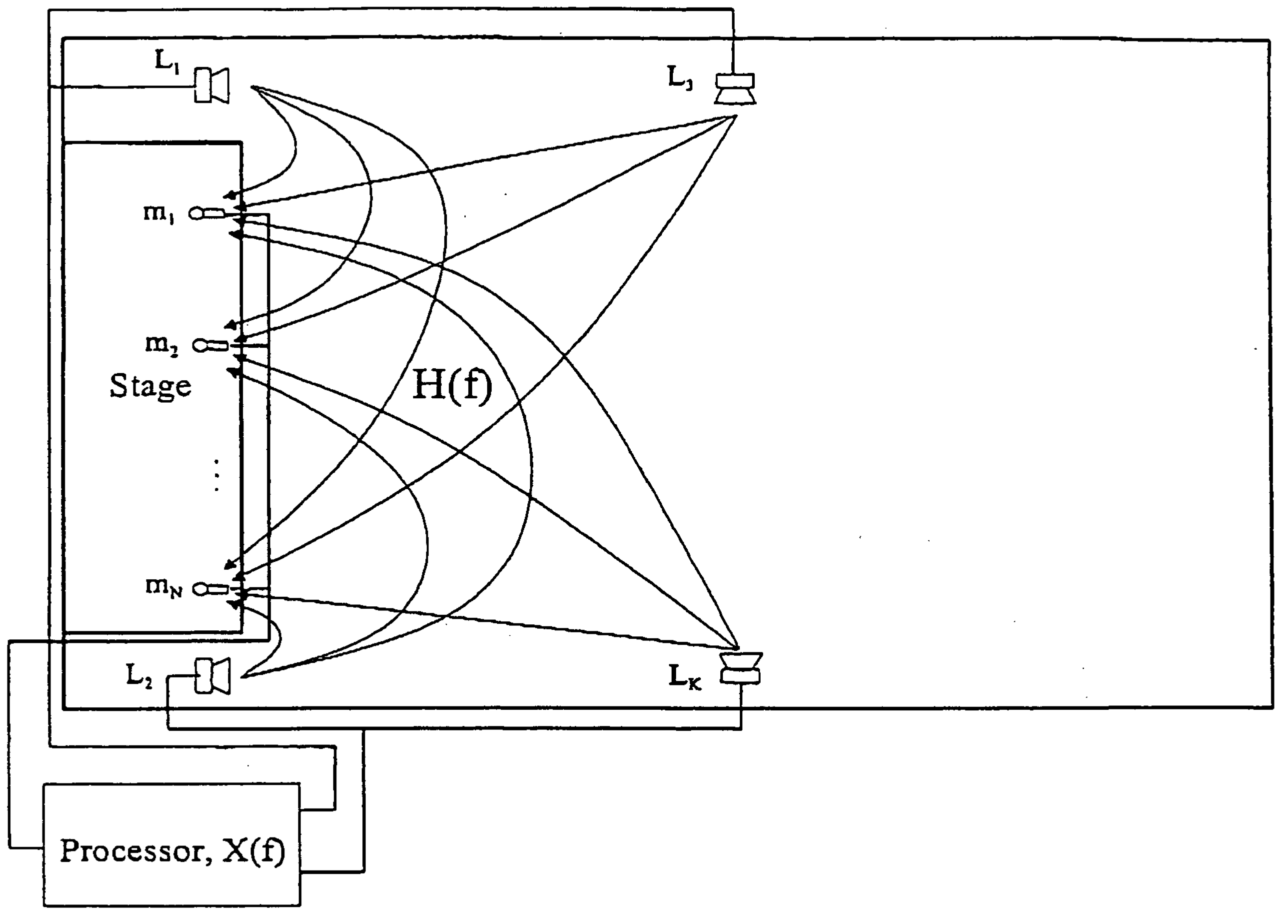

Figure 1

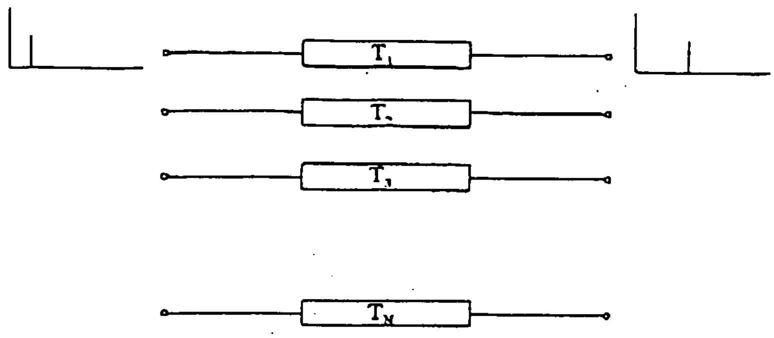

Figure 2

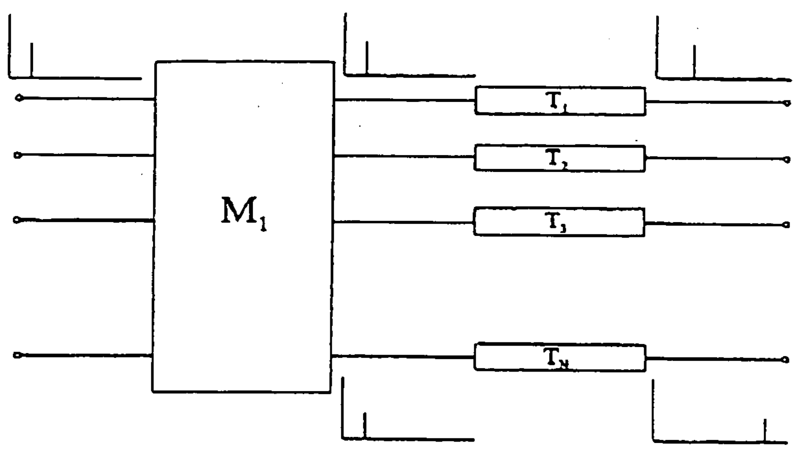

Figure 3

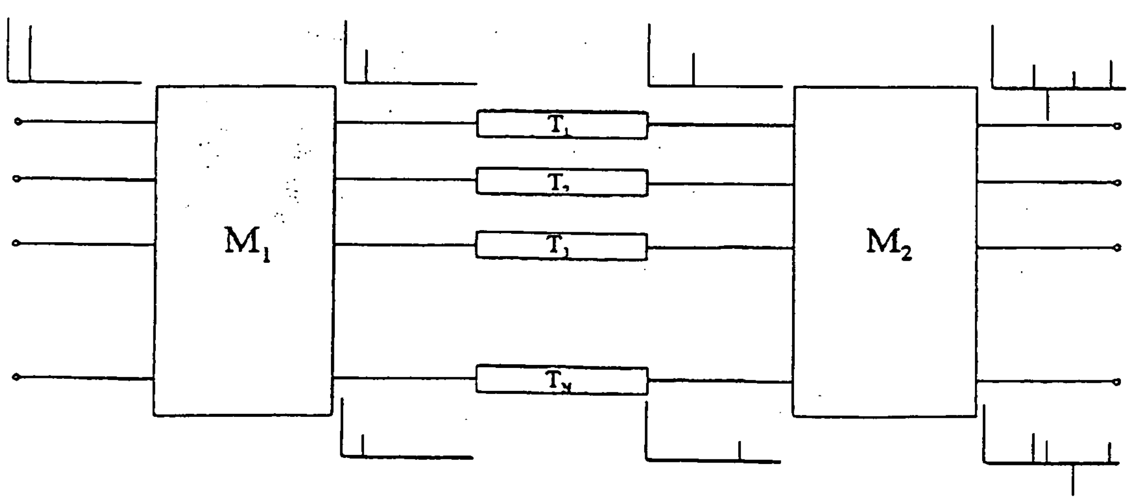

Figure 4

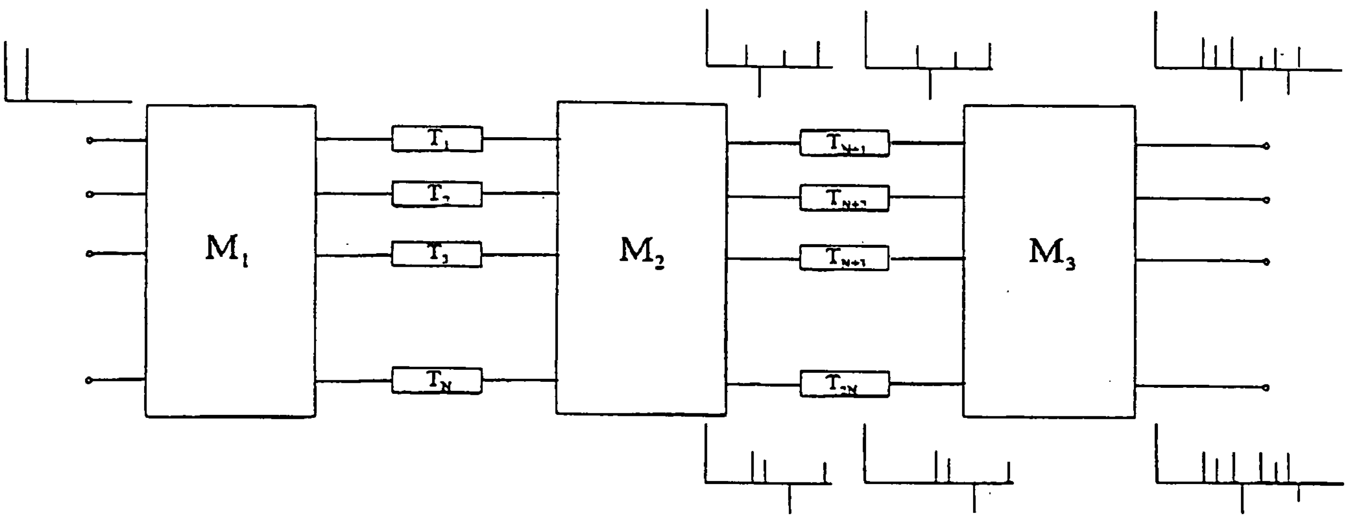

Figure 5

This Page is Inserted by IFW Indexing and Scanning Operations and is not part of the Official Record

9\18

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ BLACK BORDERS
- ☐ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☐ FADED TEXT OR DRAWING
- ☐ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☐ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☒ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☐ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: ______________________

IMAGES ARE BEST AVAILABLE COPY.
As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.